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ABSTRACT

A premature embarkation in specialized areas of fluid mechanics by the beginning graduate student, without having first thoroughly learned the basics, leads to learning difficulties and destroys zeal for learning. To avoid these problems, many schools in the U.S. offer beginning graduate courses in fluid mechanics (BGCFM). Because the success or failure of BGCFM has a profound effect on the students' subsequent learning, these courses must be planned according to specified objectives. The following include the goals of BGCFM: (1) review basic concepts; (2) introduce new concepts; (3) survey entire field; (4) learn state-of-the-art; and (5) study necessary math. At the University of Missouri-Columbia, these goals are accomplished in a series of two courses: Fundamentals of Fluid Mechanics (I) and Hydrodynamics (II). Course I is devoted to the first two goals and Course II to the last three. The specific objectives of Course I and Course II are given. The objective-oriented instruciton described involves (1) the writing of a list of goals and objectives of the course, (2) distribution of the list to students, (3) conventional teaching, and (4) reevaluation of the list at least once a year. (LS)

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"Teaching Fluid Mechanics to the Beginning Graduate Student-An Objective-Oriented Approach"

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INTRODUCTION

The success of graduate education in fluid mechanics depends to a large extent on how well students are grounded in the fundamental concepts and principles of fluid mechanics. A premature embarkation in specialized areas of fluid mechanics by the beginning graduate student, without having first thoroughly learned the basics, leads to learning difficulties and destroys zeal for learning. To avoid these problems, many schools in the U.S. offer beginning graduate courses such as "Fundamentals of Fluid Mechanics," "Intermediate Fluid Mechanics," etc. Hereafter, these courses will be referred to as BGCFM (Beginning Graduate Courses in Fluid Mechanics). Because the success or failure of BGCFM has a profound effect on the students' subsequent learning, these courses must be planned according to specified objectives. An attempt will now be made to specify these objectives.

NEEDS AND GOALS

Goals, purposes, and objectives are all derived from needs. We shall define goals as general purposes and objectives as specific purposes; thus, goals and objectives stem respectively from the general and the specific needs. What are the general needs of graduate students taking BGCFM? Although the answer to the question is bound to differ from school to school, and from person to person, I think at least one of the following five points must be at work:

1. Review Basic Concepts

Graduate students often come from different disciplines, different schools, and sometimes even from different countries. Their background in fluid mechanics is usually quite different. It is essential in the beginning to strengthen their background so that advanced subjects of fluid mechanics can be pursued later without much difficulty.

Of course, what the teacher should review must be limited to materials which are most essential to subsequent learnings and which are not yet known well enough by the student. An example is the Bernoulli equation. As said by Hansen in his book (1)*: "It (the Bernoulli equation) is perhaps one of the most used and misused equations in fluid mechanics. It is misused because the limitations inherent in its development often go unrecognized". Kline (2), in differentiating the amateur from the professional said: "The amateur wants to use Bernoulli's equation on all problems despite its legion of limitations".

These remarks attest to the widespread misuse of the Bernoulli equation by the uninitiated. The assumptions underlying the Bernoulli equation have been studied recently by Rouse (3) and Liu (4,5). Liu (5) also showed how to extend the Bernoulli equation to include non-inertial coordinates. The extended form of the equation can be used with advantage in places where fluids are accelerating as a whole (as in spacecraft) or rotating as a whole (as in turbomachines).

An equally desirable review subject for BGCFM is the integral flow equations (i.e., the integral form of the continuity, momentum, and energy

* Numerals in parentheses refer to corresponding items in references at the end of the paper.

equations). Although many recent texts intended for use at the elementary level have treated these equations rather extensively, the more advanced aspects of these equations, such as those relating to unsteady flows, non-inertial coordinates, etc., are seldom covered in undergraduate courses; thus, they must be covered in BGCFM as part of the review of integral flow equations.

A third general area, which most beginning graduate students undoubtedly know something about but not well enough to meet their needs, is the laws of similitude, inspectional analysis, and model tests. Because of the vast applicability of these subjects in engineering and science, they should be examined carefully in BGCFM.

2. Introduce New Concepts

In any group of students as heterogeneous as may be encountered in BGCFM, what constitutes a familiar concept to one student may often be a brand new idea to another. This points to the difficulty in selecting appropriate materials for teaching. Notwithstanding the difficulty, after having taught the same course a couple of times at the same school, it is usually not too difficult for a teacher to tell whether a subject is new to most students. A chat with the class, and/or asking each student to fill out a questionnaire on the first day of the class, may also reveal valuable information.

In the writer's opinion, the most disatrous mistake the teacher of BGCFM can make is to assume that all those materials contained in ordinary undergraduate fluid mechanics texts are already known to beginning graduate students. The assumption is false, because practically all undergraduate texts in fluid mechanics contain more materials than can be covered in a

three-semester-hour course. Although most students may have had a second or even a third course in fluid mechanics during their undergraduate years, the follow-up courses are usually confined to one or two specific branches (e.g., open-channel flow for the civil engineers, etc.). Many subjects contained in undergraduate general fluid mechanics texts--the more theoretical stuff, such as the general relationship between stress and strain in viscous flows, the Navier-Stokes equations, etc.--usually never find their way into undergraduate teaching. They are usually left out intentionally to make room for subjects believed to be more practical, and hence more relevant, to the mission of undergraduate education. Consequently, these more theoretical basic concepts and equations must be discussed in detail in graduate school.

3. Survey Entire Field

Students taking BGCFM often have a burning desire to learn a little of everything about fluid mechanics as quickly as possible. What is potential or irrotational flow? Where do we find it? How are complex variables used for solving potential flow? How is turbulent flow treated differently from laminar flow? What is an eddy viscosity? What does Prandtl's mixing length hypothesis say? What basic analyses are involved in boundary layer theory? How are the transports of heat, mass, and momentum related to each other? These are a few of the many subjects that may partially satisfy the student's hunger and thirst for learning.

Clearly, it is impossible to conduct an in-depth study of all the areas of fluid mechanics in just one or two courses. Nevertheless, enough information about each area may be included in one or two courses to give the student a good overall view of the field.

4. Learn State-of-the-Art

Most students also have a strong desire to know what the state-of-the-art is with respect to various important subjects of fluid mechanics. For instance, what is the state-of-the-art in numerical solution of the Navier-Stokes equations using large computers? What is our current understanding about the so-called laminar sublayer? How successful can one predict turbulent boundary layers using various semi-empirical schemes? These are subjects that are not only important but also stimulating. Their inclusion in BGCFM goes a long way toward motivating the beginner.

5. Study Necessary Math

It is not uncommon to find Ph.D. candidates in fluid mechanics who have taken more courses in mathematics than in their own major fields. This shows the heavy reliance of fluid mechanics on mathematics. But since a graduate student cannot afford to wait until he has taken all relevant advanced math courses before starting on fluid mechanics, important math concepts and techniques needed in fluid mechanics must be introduced to the student in BGCFM.

What one must keep in mind in teaching mathematics in fluid mechanics is that mathematics is the tool not the goal. As it is so, only what is absolutely essential to the pursuance of fluid mechanics should be included. Extravagant use of mathematics, as often found in the literature of fluid mechanics, is a major demotivating factor and hence should be avoided. The purpose of using mathematics should be to enlighten rather than to confuse the student. The math should not be crammed into the first three weeks of the course. Instead, it should be spread over the

semester, given to the student bit by bit, as an integral part of fluid-mechanics teaching.

Teachers of BGCFM can safely assume that all students taking the courses have at least some knowledge of vector algebra and differential equations. Consequently, extensive review of these subjects is unwarranted. On the other hand, subjects of vector calculus, such as the Stokes theorem and the like, are usually new to the beginning graduate student and should be expounded thoroughly. Other math subjects that should be thoroughly explained before used include Fourier series and Fourier integrals, eigenvalue problems, complex variables and conformal mapping, numerical analysis (the finite difference technique), and various ways to solve partial differential equations analytically.

As to tensor analysis, extensive use of it in BGCFM is undesirable. It may cause learning difficulty and do more harm than good to the uninitiated. In the writer's opinion, the only place where tensor is justified in BGCFM is when dealing with quantities that are tensors of the second or higher ranks. Even then only the simplest aspects of tensor need to be introduced. The use of tensor in BGCFM should be no more than a shorthand listing of results already derived in one scalar component. Extensive use of tensor should be reserved for upper-level graduate courses, after the student has taken BGCFM and/or a course in tensor analysis.

ARRANGEMENT OF COURSES

Clearly, not all the five aforementioned goals can be accomplished in a single three-semester-hour course. At the University of Missouri-Columbia, they are accomplished in a series of two courses: CE460 Fundamentals of Fluid Mechanics (3hrs.), and CE464 Hydrodynamics (3hrs). Hereafter, they

will be referred to, respectively, as Courses I and II.

The main purpose of Course I is to achieve the first two enunciated goals, namely, to strengthen the student's understanding of basic concepts and teach him important new concepts of fluid mechanics. The emphasis of the course is on physical concepts rather than mathematical theories. An unpublished textbook has been used in this course. The book first lays out many basic concepts such as the Lagrangian and the Stokes stream functions, vorticity and circulation, relative velocity and non-inertial coordinates, etc. Then it goes into a systematic examination of the continuity, momentum, and energy equations in integral forms. The examples used to illustrate these equations are generally at a level higher than those used in undergraduate courses. Otherwise, the approaches used to solve problems are of a caliber higher than those used in undergraduate texts. The book also derives the differential forms of the continuity, momentum and energy equations, and discusses the basic features and the usefulness of these equations. Throughout the book, much emphasis is placed on clarifying misconceptions widely held by the uninitiated, such as the misuse of the Bernoulli equation mentioned before. Finally, the subjects of dimensional and inspectional analyses and the theory of model test are thoroughly treated.

Course II is devoted to the last three of the five aforementioned goals. The course has been taught without a text (one is under development). Although the emphasis of Course II is still on physical rather than mathematical concepts, much more math had to be included than in Course I. An effort is made to introduce the important math techniques needed for the solution of potential and viscous flow problems. This

includes both numerical and analytical techniques for solving partial differential equations, such as conformal mapping, finite difference methods, separation of variables, Laplace transforms, similarity methods, etc. The course also goes into the state-of-the-art of various subjects, and describes important recent developments in fluid mechanics, such as the concept on the inner and the outer laws of turbulent boundary layers, the large computer programs to solve Navier-Stokes Equations, the Stanford competition in computing turbulent boundary layers, prediction of diffusion and dispersion of pollutants in waters and the atmosphere, etc.

At UMC, Course I is offered in Fall while Course II follows it in Spring. Although both courses are offered by the Department of Civil Engineering, students taking the courses often come from a wide spectrum of fields encompassing atmospheric science, mechanical and aerospace engineering, chemical engineering, agricultural engineering and, of course, civil engineering. While the principles discussed in the courses are about the same each year, examples used differ widely from year to year to reflect student composition. Responses from students, as reflected in results of teacher evaluations conducted at the end of each semester, were encouraging.

SPECIFIC OBJECTIVES

Part I: (Pertaining to Course I and the first two of the five goals set forth before.)

1. He* should be able to know** the difference between the Lagrangian and the Eulerian views of description, and be able to cite several examples of each used in fluid mechanics.

2. He must know the difference between system and control volume, and be ready to cite examples of each. He should be able to give examples of deformable as well as non-deformable control volumes, stationary as well as moving control volumes. He should always clearly specify the control volume used in any analysis.

3. He must know what a non-inertial coordinate system is and why we sometimes use it, how Newton's second law changes when non-inertial coordinates are involved, what non-inertial terms are caused by coordinate acceleration and what are caused by coordinate rotation, why one considers only the Coriolis term not the centrifugal term in atmospheric and oceanic motions, how the non-inertial terms can be considered as body forces, whether they are conservative or non-conservative forces, how does one include the non-inertial terms into various equations of fluid mechanics, etc.

4. He should be able to cite several types of unsteady flows that can be transformed into steady flows by employing a moving (inertial or non-inertial) coordinate system. Likewise, he should be able to give examples of unsteady flows that cannot be transformed into steady flows. He should know the various approaches available for solving unsteady flows and be able to work practical problems using these approaches.

5. He should know the differences between body and surface forces, and be able to name all types of body and surface forces and the distinct features of each. He should know when gravity can be regarded as constant and when it cannot, how gravity and centrifugal force vary around the earth, how this affects the equilibrium distribution of water over the earth, the nature and the mechanism of the tide-generating force, the types of flows in which one must consider the electric and magnetic forces, how one incorporates them into flow equations, what the basic features of surface tension is and how one treats surface tension in fluid mechanics, etc.

6. He should be able to convert any equation from Cartesian coordinates to cylindrical and spherical coordinates. He should know the difference between the kind of spherical coordinates ordinarily used in fluid mechanics and the kind used in geo-

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* The word 'he' refers to the student, both male and female.

** By 'know' we mean: be able to demonstrate or describe, orally or in writing, in a clear manner.

physics. He should know the basic features of the streamline coordinates and the general orthogonal curvilinear coordinates (GOCC), and be able to reduce any equation from GOCC to Cartesian, cylindrical, or spherical coordinates. He should know when it is more advisable to use one type of coordinates than another and why.

7. He must know what are streamlines, pathlines, streaklines, and timelines, and the differences between them. He should be able to form a mental picture of these lines, and know how to generate them in a thought experiment of flow visualization. He must know the equation of streamline in each coordinate form.

8. He must know what the Lagrange and the Stokes stream functions are, the conditions under which each of the two stream functions exist, whether they are for potential flow only or can they be used for both potential and viscous flows. What is the purpose of defining a stream function, and for what are stream functions used? He also should be able to get velocity fields from stream functions and vice versa.

9. He should be able to explain the differences between particle acceleration, local acceleration, and convective acceleration, through the use of examples and equations. He should be able to write these accelerations in different coordinate forms.

10. He should be able to derive the expressions for linear and angular deformations, and for rotation of fluid. He should know how acceleration is related to deformations and rotation.

11. He must know the difference between vorticity and circulation, and the relationship between them. He should know what an irrotational flow is, and whether there can be any circulation and vorticity in irrotational flow. He must know the Stokes theorem of vector calculus and how it is related to the study of vorticity and circulation. He must know the analogy between vortex lines and streamlines, and between vorticity and velocity vectors.

12. He should be able to name the three basic laws and most auxiliary laws or constitutive equations of fluid mechanics.

13. He should know what a stress tensor is, what its nine components are, and how to illustrate them on a cubic element in space. He should know why the stress tensor is symmetric. He should also know the essence of Stokes' law of viscosity, and the concept of pressure (the average normal stress) in viscous flows.

14. He should know the general system-to-control-volume transformation equation. (This means he should understand the derivation, know the meaning of each term, see the implication, and be able to use the equation for the derivations of the continuity, momentum, and energy equations in integral forms.)

15. He should be able to recognize readily the various forms of the continuity, momentum, and energy equations in integral and in differential forms, and to recall readily the assumptions underlying each of the equations. He should know when to use which equation.

16. He should be able to use the integral flow equations skillfully. For instance, he should be able to use these equations to solve problems involving non-inertial references and moving deformable control volumes. He should also be able to use these equations to handle certain unsteady flows and flows involving heat transfer.

17. He should know how the Euler and the Navier-Stokes equations are derived, and the assumptions behind each of the equations. He must know certain general characteristics of the two equations, such as: What are the orders of the equations? Are they linear? Which are the nonlinear terms and why? What makes linear equations special? Is the no-slip condition compatible with the Euler equations and why, etc. For a clearly stated problem, he should be able to point out what terms in the Euler or the Navier-Stokes equations vanish and what terms do not, and he should be able to specify the boundary and initial conditions of the problem in mathematical terms. Finally, he should be able to solve certain simple problems using the Euler or the Navier-Stokes equations.

18. He should be familiar with the various forms of the Bernoulli equation, including even those for unsteady compressible flow with non-inertial coordinates. He should know clearly the limitations of each form of the Bernoulli equation, and be able to use the equation to solve practical problems.

19. He should be familiar with the concept of the work done by shear and pressure, and the relationship between work, heat and energy in flow in general and along a streamline in particular. He should know what dissipation function means. He should know the physical meaning of each of the terms of the energy equation in differential form, and be able to use the equation to determine the temperature distribution of simple flows such as the Couette flow.

20. He must know the essence of dimensional analysis. He must know Buckingham's pi-theorem, and be able to use it to derive a desirable set of dimensionless parameters (the pi-parameters) once the problem variables are given and the purpose of the study is known. He must know all the important pi-parameters in fluid mechanics, including the Reynolds, Froude, Mach, Euler, Cavitation, Weber, Prandtl, Eckert, Brinkman, Schmidt, Rossby, and Richardson numbers. For any given type of flow, he must know which of these parameters ought to be used and which can be neglected.

21. He must know the linkage between similitude and model tests, and know the role played by pi-parameters in any model tests. He must know what dynamic and kinematic similarities mean, how to achieve them, what a 'scale effect' is, what kinds of scale effects one usually encounters in model tests. He must also know the reasons for, and the limitations of, using distorted models.

22. He must know the essence of inspection analysis, and its relationship with dimensional analysis and model tests. He should be able to apply inspection analysis to practical problems.

Part II: (Pertaining to Course II, and the last three of the five goals set forth before.)

1. He must have a clear concept on potential flow. This means he must know what a potential flow is, where can it be found, what the equations governing potential flow are, what the Cauchy-Riemann condition is and what it has to do with potential flow, what roles do Laplace and Bernoulli equations play in potential flow theory, etc.

2. He must know why is it permissible to combine solutions of the Laplace equation linearly to generate new solution--the method of superposition. With this method, he must be able to use a sink, a source, a free vortex, and a uniform flow to generate a host of other flows such as those around a cylinder or sphere (with or without rotation), doublets, Rankine ovals, flow around bodies of revolution of any shape, etc. He also must be able to use the method of image to augment the power of the superposition method.

3. He must know how complex variables and conformal mapping are used to solve two-dimensional incompressible potential flow. First of all, he must know some basic operational properties of complex variables, such as: how to add, subtract, multiply, divide, take the power of, take the absolute value or argument of, take the complex conjugate of, and take the derivative of complex variables. He must know what an analytic function is and when functions of complex variables are analytic. He must know how to slit an analytic function of a complex variable into a real and an imaginary part. He must know how to combine a stream function and a potential function to form an analytic function of complex variable--the complex potential. He must know how to use the complex potential to get the x and y components of the velocity without having to determine the stream function and the potential function first.

4. He must know what conformal mapping is and what is conformed in such a mapping. He must have a clear conception of the interplay between conformal mapping, complex variables, analytic functions, and potential flow. He must be able to transform a point, a line, and an area from one plane to another once the transformation equation is given. He must know the properties of a few important transformation equations such as the Joukowski transformation. Above all, he must know how conformal mapping is used to find the complex potential of flows.

5. He must know what the hodograph method is, what it is for, and how is it related to conformal transformation. He should be able to draw the hodographs of a few simple free surface flows, and to use the results for the determination of flow fields. He should know the type of problems that can be solved by the hodograph method.

6. He should know the techniques of flow net, membrane analogy, and electrical analogy of potential flow. He should know how to solve the Laplace equation numerically--how to construct a grid, how to get the finite difference equations, and how to solve them on a digital computer.

7. He should know a few things about compressible potential flow--the governing equations and the solutions of a few simple cases, such as the acoustics wave equation.

8. He must have an overall picture of the field of incompressible viscous laminar flow. He should know what constitutes an exact solution and an approximate solution, i.e., the criterion that separates an exact from an approximate solution in this field. He should be aware of many classical exact and approximate solutions of viscous laminar flow, including the general solution for parallel flow in conduits of arbitrary cross-sectional shape, parallel flow along a suddenly accelerated plate (Stokes first problem), unsteady Couette flow, flow between convergent or divergent plates, three-dimensional stagnation flow, creeping flow, Hele-Shaw flow, flow around a sphere (Stokes solution), etc. He should know how each of these problems was solved.

9. He must learn many important math techniques used in the solution of viscous flow problems, such as separation of variables, Laplace transform, similarity methods, etc. He should know the power as well as the limitations of these techniques. He should know when a technique is applicable, when it is not, and why.

10. He should have some idea of the basic concepts and the state-of-the-art of numerical solution of the Navier-Stokes equations using large digital computers. This includes a knowledge of the different choices possible in the selection of a numerical scheme: whether to use a Lagrangian or an Eulerian viewpoint, whether to use stream function and vorticity, or velocity and

pressure as dependent variables, etc. He should also know the availability of certain computer programs such as the SMAC (Simplified Marker-and-Cell) and the PIC (Particle-In-Cell) methods developed at the Los Alamos Scientific Laboratory.

11. He must have a clear concept of boundary layer analysis. He must know what a boundary layer is, and what boundary-layer thickness, displacement thickness, and momentum thickness are. He must know the basic boundary layer equations, and how they were derived. He must know how the pressure distribution along a boundary layer can be determined--the relationship between boundary layer analysis and potential flow. He must know the details of the Blasius solution of the boundary layer along a flat plate. Given the velocity distribution in the boundary layer, he should be able to draw a suitable control volume and apply the momentum and the continuity equations in integral form to the control volume to predict the variations of boundary layer thickness and skin friction coefficient along the plate.

12. He must have the same understanding and be able to do the same types of analyses as specified in Item 11 with respect to thermal boundary layer.

13. He must have some knowledge of certain important analyses made in turbulent flow. First of all, he must know how to characterize turbulence by using statistical quantities such as root-mean-square, spectrum, probability density, probability distribution, correlation functions, correlation coefficients, etc. Next, he must know the Reynolds averaging process, and be able to apply it to the Navier-Stokes equations in order to get the turbulent stresses, leading to the definition of eddy viscosities. Finally, he should understand the conceptual model used by Prandtl in the derivation of the mixing length theory, and be able to explain what this theory or hypothesis is all about and its application.

14. He should know the velocity distributions in turbulent shear flows. He should know what the inner and the outer laws are, what makes the two different, what the so called "laminar sublayer" is, where the logarithmic velocity distribution predicted from mixing length hypothesis exists, what the Von Karman constant is, whether it is really a universal constant, what are the dimensionless parameters characterizing the inner and the outer laws, etc.

15. He should know the state-of-the-art in predicting turbulent boundary layer as can be seen from the celebrated 1968 Stanford competition. He should be able to describe briefly the general approaches used by researchers nowadays to predict turbulent boundary layers.

16. He must know what Fick's law is and how it can be used to derive the diffusion and the convective-diffusion equations. He must be able to apply the Reynolds averaging process to the convective-diffusion equation to get a turbulent convective-diffusion equation in terms of turbulent diffusion coefficients.

17. He must understand the essence of Taylor's theory of diffusion by continuous movement--in what types of turbulent flow the theory holds, how diffusion proceeds with time in the beginning and how does it proceed after a while, what are Lagrangian velocity fluctuations, Lagrangian correlation coefficient, and Lagrangian time scale, how are they related to the corresponding Eulerian quantities, how is Taylor's result related to the turbulent diffusion coefficient, etc.

18. He should know the difference between diffusion and dispersion. He should know what causes longitudinal dispersion, and how can we predict the dispersion of pollutants in rivers, lakes, etc.

19. He must know the analogy between the diffusions of mass, heat, and momentum in turbulent flow, and the relationships between the turbulent diffusion coefficient, turbulent heat diffusivity, and the eddy viscosity. He must know what turbulent Prandtl and Schmidt numbers are, and the approximate magnitudes of them. He must know the analogy between skin-friction coefficient and the heat transfer coefficient at wall.

OBJECTIVE-ORIENTED INSTRUCTION

The writer's involvement in objective-oriented instruction started in 1972 when he attended the 6th Midwest Effective Teaching Institute sponsored by ASEE at the Lake of the Ozarks. One of the two sessions of the institute was "Objective-Oriented Instruction." It was organized by Dr. LeFevre of the University of Arkansas, using a workshop manual (6) he and Dr. Thatcher used earlier at the 1972 Annual Meeting of ASEE at Lubbock, Texas. According to LeFevre and Thatcher, Objective-Oriented Instruction (OOI) is a special pedagogical method "carefully designed to lead the student to achieve a prescribed set of written objectives." The method requires (1) writing a set of course objectives for each instructional unit or module, (2) designing an appropriate instructional program in order

to pursue the objectives, and (3) measuring student accomplishment of objectives.

The OOI method devised by LeFevre and Thatcher owes much of its origin to "Taxonomy of Educational Objectives," a publication of a committee of college and university examiners (7), and "Dimensions for Measurement of Teaching," a report of an ASEE committee (8). The method heavily emphasizes testing and evaluation. It requires all course objectives to be written not only in great detail but also in measurable terms. Because most teachers like their role as "learning facilitators" far better than as "testers", it is questionable if any method with heavy emphasis on testing and evaluation will ever catch on, especially in graduate circles.

The method used by the writer at the University of Missouri-Columbia is a more flexible version of OOI. It involves (1) the writing of a list of goals and objectives of the course, (2) handing the list to the students at the beginning of the semester and inviting them to comment at the end of the course, (3) teaching the course in a conventional manner while keeping the written objectives in mind all the time, (4) reconsidering the goals and the objectives from time to time and reevaluating the list at least once a year.

As seen from the above description, the OOI method used by the writer really does not attempt to change the traditional lecture method of instruction drastically. It merely reforms the system by requiring the teacher to think harder about the goals and the objectives. The method used is simple and flexible. The only requirement is that the teacher draws up a list of goals and objectives, distribute the list to students and colleagues, and invite their comments.

The need for writing down goals and objectives rather than simply keeping them in mind is obvious. The thoughts in our heads are often muddled and contradictory; without putting them on paper we cannot inspect them rigorously. They cannot be inspected rigorously by others either unless we have laid them out clearly on paper. In short, writing is necessary for rigorous thinking and critical evaluation.

In writing down the goals and objectives of any course, we must ask ourselves a host of questions: What purposes does the course serve? What is the general background of the class and what do the students want? How does this course relate to the mission of the institute? How does the course relate to, and differ from, the other courses in the same discipline offered at the same institute? What subjects are usually included in a course like this at other institutes? What subjects are most likely to be relevant to the student's future tasks in learning, research, and professional work? What is the future and the changing direction of the field? etc. A well-designed set of goals and objectives should take all these matters into consideration and should serve the greatest needs of both the student and the institute. It should be written in clear, explicit, and behavioral terms; it is not a simple listing of the course content. Finally, potential advantages of OOI are:

1. As the goals and the objectives of a course become clear to the teacher, more relevant materials get included in the course.
2. Not all subjects covered in a course should receive equal attention from the student. The list of goals and objectives indicates the points of emphasis of the course.
3. By making goals and objectives clear to the student, learning becomes much more meaningful and the student becomes motivated. This point was well explained recently by Ablin and Flammer (9).

CONCLUSION

Teaching without goals and objectives is like shooting without a target. In shooting it is not enough just to keep your target in mind, you must see the target clearly. Likewise, it is not enough merely to consider the goals and objectives in teaching, you must state them clearly on paper. This is a point that cannot be overemphasized.

As illustrated, OOI can easily be used in association with the conventional lecture method, to make the latter more meaningful and effective. Although OOI can be used with advantage in all courses, those that may benefit the most are courses that have not yet evolved into a definite pattern. This includes new courses, ephemeral courses, interdisciplinary courses, and transitional or preparatory courses. The beginning graduate courses in fluid mechanics (BGCFM) is a particular example of transitional or preparatory courses. They ensure a smooth transition from undergraduate to graduate education. Therefore, it seems highly appropriate to use an objective-oriented approach in teaching BGCFM.

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